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Preliminary Study of the
Waters of the Jemez Plateau,
New Mexico



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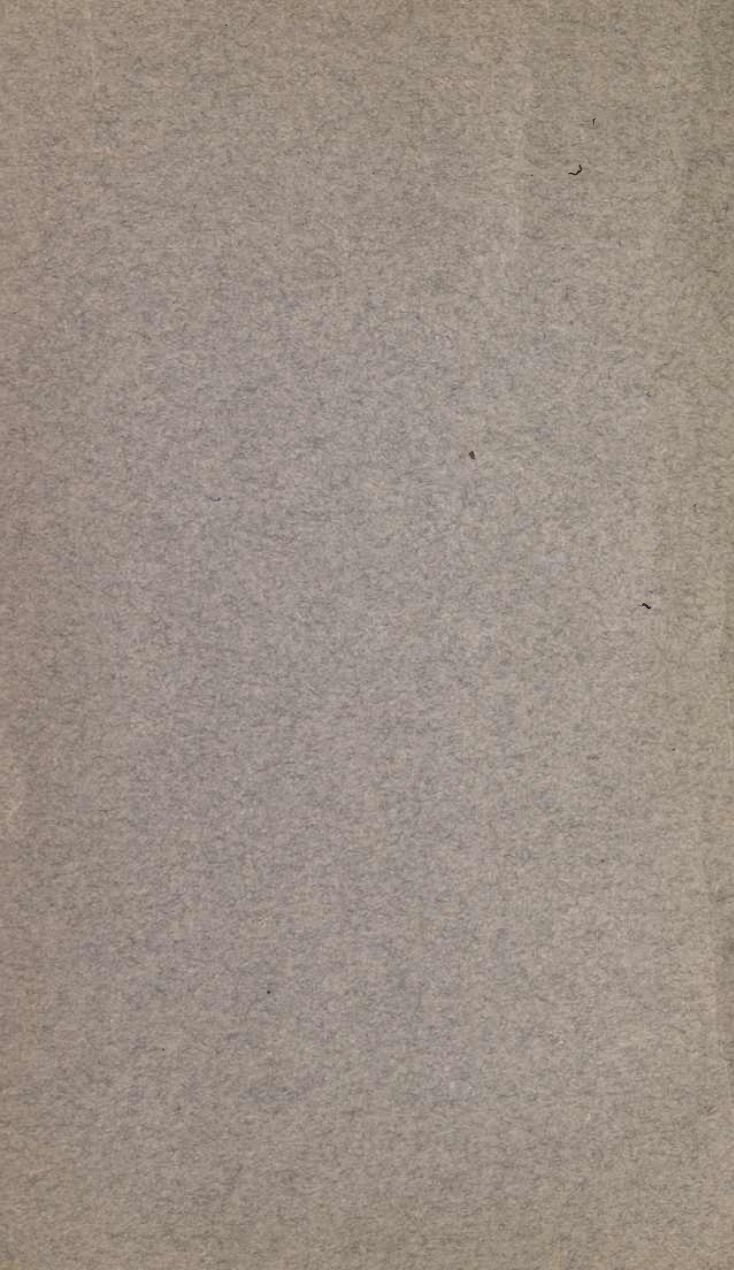
A PRELIMINARY STUDY OF THE WATERS OF THE JEMEZ PLATEAU, NEW MEXICO

-BY-

Clyde Kelly and E. V. Anspach
Class of 1913

ALBUQUERQUE, NEW MEXICO
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INTRODUCTION.

The region to which the name "Jemez Plateau" is applied in this paper is situated in the northwestern part of New Mexico. It extends from a point almost due west of the city of Santa Fe northward to the Colorado line, a distance of about ninety miles. Its breadth at its widest part is about sixty miles. The plateau is divided unequally by the Rio Chama which flows through it from the northwest to the southeast. The southern, or larger division is loosely known as the "Jemez". The western limit of this part is the Rio Puerco; its eastern limit is the Rio Grande. It contains two important ranges of mountains, the Nacimiento range in the west, and the Cochiti mountains

in the east. The highest peak of these mountains has an altitude of 11,200 feet.

Between the Nacimientos and the Cochitis there is a flat mesa or table-land of an altitude of from 7,000 to 8,000 feet. The northern part of this, approximately one-third, is drained by tributaries of the Rio Chama. The southern part is drained by the Jemez river and its tributaries. The Jemez empties into the Rio Grande. It is in this southern part of the plateau that the different groups of springs, whose waters form the subject of study of this paper, are found.

PHYSIOGRAPHY OF THE JEMEZ DISTRICT.

The leading physiographic features of the Jemez district are the mountains, which are characterized by their rounded contours, flat mesa lands cut by numerous cañons, and valleys extending along the lower courses of the streams. The whole country shows the effects of having been extremely broken up at some former time. There are few hills in the region, but hogbacks, dikes, escarpments, and fault lines are numerous. As a rule the cañons follow the fault lines. Along the lower course of the Jemez river, after it leaves the protection afforded by the mountains, sand dunes have been piled by the prevailing winds.

Mt. Pelado, or "Baldy" as it is commonly called, with an elevation of 11,200 feet, is the culminating point of the plateau. It is a solid mass of porphyry and is situated at the northern end of the Cochiti range and immediately west of the Valle Grande tufa volcanic region. The site of the crater today is a level

area. A further reference to Mt. Pelado will be made later.

Much of the upper country of the plateau is covered by tufa, while basalt, usually of the "malpais" type, caps and flanks many of the lower mesas.

The tributaries of the Jemez river have their origin in the high rhyolitic plateau of the Nacimiento and Cochiti mountains. Here, they are mountain streams which usually have water in them. In their lower courses, however, the water seeps into the sands and their channels are always dry. On leaving the mountains each tributary has cut a deep, narrow cañon varying in depth from a few feet in the upper part to 1,200 feet in the lower course. The upper part of each cañon is cut in Carboniferous rock; the lower part is in the Red Beds (Permian). At Cañon de los Jemez, the Guadalupe and San Diego creeks, having gathered in all of the upper tributaries except Vallecito creek, unite to form the Jemez proper. At this point the united river enters the site of an ancient Cretaceous lake.

According to Reagan, there are deposits of Jurassic-Cretaceous age in the area south of the Red Beds, and, as the dip of the Carboniferous and Red Bed strata has remained unchanged, so far as direction is concerned since the Red Bed revolution, it is probable that the streams existed as far back as the Jurassic-Cretaceous age or even earlier.

After uniting with Vallecito creek, the Jemez continues in its southward direction until its confluence with the Rio Salada. It then flows eastward along the

southern limit of the Plateau and unites with the Rio Grande near the village of Bernalillo.

The mountains of the district for the greater part are forested by pine, fir, spruce, and aspen. None of the peaks extend above the timber line, although some of them are bare. In most cases these barren spots can be attributed to denudation by forest fires.

The mesas are rather thinly covered with piñon, juniper, and cedar, interspersed with small open parks. The valleys produce sage, cactus, and chaparral. In the lower valleys, the Mexicans and Indians raise corn, beans, chili, and other farm products. Fruit raising is also carried on on a small scale.

THE SPRINGS.

Along the lower part of the Rio Salada and in the upper Jemez river there are many springs, some hot, some cold, and some of a bathing temperature. The waters of all of these springs possess medicinal properties; and the principal springs have been health resorts since the invasion of the white man. These springs seem to be in groups. The principal groups are: the Sulphurs, the Springs of the Soda Dam in the Jemez river, the Jemez Hot Springs at Perea, the Indian Springs, the San Ysidro Springs, and the Phillip's Springs. These groups are here considered in the reverse order.

THE PHILLIP'S SPRINGS.

The Phillip's springs are forty in number. They are situated in a little cove between the granite spur to the southwest of the Nacimiento range and the Red

Beds to the west of the Jemez on their western side. The space occupied by them is not greater than thirty acres, though at an earlier date their area was much more extensive than now, as is attested by the travertine cones left by the extinct springs. The cove occupied by these springs is about a mile to the northeast of the Rio Salada, and eight miles nearly west of the Jemez Pueblo. The springs of this group are soda or iron springs. The soda springs deposit a cone of travertine around their mouths, and the iron springs are non-depositing. The springs of this group usually have a bathing temperature; but they are not used for bathing purposes on account of their isolation, though their site would make an excellent place for a health resort. They are situated on the Ojo del Espiritu Santo Land Grant.

THE SAN YSIDRO SPRINGS.

The San Ysidro springs are situated on either side of the Rio Salada in its lower course, their waters coming to the surface along a fault. They are some forty in number. Those to the south of the river are bitter magnesium, and those to the north are soda springs. The waters of the springs are cold. They have medicinal properties; and throughout the summer months the Mexicans bathe in them. These springs, being on salt lands, belong to the University of New Mexico, because all the salt lands of the state have been reserved for the benefit of that institution.

Loew, in "Analysis of Mineral Springs," Volume III of the U. S. Geographic Surveys of the Territories,

gives the analysis of waters from these springs as follows:

Specific Gravity	1.0023	
The mineral matter in 100 parts of water:		
Carbonate of sodium.....	0.3072	
Sulphate of soda.....	0.1639	
Carbonate of lime.....	0.0670	
Carbonate of magnesia.....	0.0243	
Carbonate of iron.....	0.0008	
Potassa	}	
Lithia		traces
Silicic acid		
	0.5632	

THE INDIAN SPRINGS.

These springs extend in an east and west direction in a narrow belt of land about a mile to the north of the village of San Ysidro. At their west end they extend along a fault; and it is probable that the eastern springs of the group are also the result of a fault. In the eastern part, the fault, if present, is covered by later deposits. The springs are alkaline but do not deposit sinters. They are cold in the west but increase in temperature toward the eastern part of the belt. The temperature of the eastern springs, those to the east of the Jemez river, is about 120 degrees Fahrenheit. They are being covered continually with debris brought down by an eastern arroyo and must be dug out when used. The Indians use these springs almost continually during the summer months; even the Isleta Indians, south of Albuquerque, come here

to bathe for their ailments. The springs are on Indian lands, whence the name.

THE JEMEZ HOT SPRINGS.

The Jemez hot springs, or "Ojos Calientes," as the Mexicans call them, are situated in the Jemez river bed in Cañon San Diego at Perea. The site is a beautifully picturesque one. The Red Bed walls of the cañon rise 1,200 feet on either side of the river, while in the valley, a little above the springs, are the ruins of the Indian village of San Juan de los Jemez and of the Spanish Catholic church and fortifications of the first occupation of the Spaniards.

These springs are located geographically in two groups. At each group are built comfortable bath houses and sweating rooms. Hotels have been erected for the benefit of health seekers. A daily stage runs between the springs and Albuquerque. The springs are known throughout America and in Europe and occasionally one meets a foreigner here.

THE SPRINGS OF THE SODA DAM.

The Soda Dam, which lies about a mile above the Jemez Hot Springs, is a travertine ridge built directly across the Jemez river. It is about three hundred feet long, fifty feet high at its highest part near the east end, fifty feet wide at the base, and twenty-five feet wide at the top. The river was, at one time, completely dammed by the Soda Dam, but later it cut its way around the east end, and today flows over the dam underneath a large dome, which has been built out over the river by the deposits of a spring on top of the dam.

In the *American Geologist*, Volume 31, Reagan states that there were twenty-two springs situated on the dam in 1902. While there are indications of many recent active springs on top of the dam, the authors were unable to find more than half this number when they visited the region in 1912.

All the springs deposit travertine and their waters running over the dam cause the cap of the dam to be built farther up and out each year, thus leaving rooms beneath the cap. These rooms are decorated with stalactites suspended from the roof. They are exceedingly picturesque.

On and about the dam are numerous siliceous cores of concentric layers of silica. They are from one-half inch to several inches in diameter and from an inch to several feet in length. The waters, which formerly came up through the center of the cores, have kept depositing their silica until the vents were entirely closed, thus forming the siliceous core.

In the *American Journal of Science*, 3d series, volume 7, 1889, page 351, Mr. W. H. Weed, who has studied the formation of sinters in the Yellowstone Park, states that the deposit may be due, either to relief of pressure, to cooling, to chemical reactions between different waters, to simple evaporation, or to the action of algae. In the last case the silica forms a gelatinous layer upon the algal growths, and this, after the death of the algae, gradually hardens to sinter. While all of the above actions have taken place on different parts of the dam, the actions which have formed the siliceous cores are the relief of pressure and cooling of the

water. Since the cores have formed under the surface of the ground, their formation could not be due to evaporation or to the action of algae, as algae are found only at some distance from the mouth of the springs on the surface.

Because the waters from the springs on the dams are strongly alkaline they carry large amounts of silica when under pressure and, as soon as this pressure is removed, a large amount of the silica is deposited, forming the cores.

The waters of the springs come to the surface after encountering a granite wall in their southern course, which crosses the country in an east and west direction; hence the line of springs.

Reagan gives the geology of the dam as follows:

“These springs existed in former geologic time and then dammed the river with their deposits the same as today. The remains of the first dam is nearly one thousand feet above the present one; and, as the river has cut its channel down, a succession of dams in step-like order has been formed. These dams, therefore, are evidence that Cañon San Diego was not formed altogether by a faulting of the strata; but that the Jemez river has here chiseled out for itself the present channel. They also indicate that the Jemez plateau has been raised by a series of uplifts, each dam marking the period of rest.”

THE SULPHURS.

To the north of Pelado, about thirteen miles northeast of the Soda Dam and the Jemez Hot Springs, on

the very top of the Jemez Plateau are the famous sulphur springs and still further to the northeast are the San Antonio springs. The latter attain a temperature about the same as that of the Indian springs to the east of the Jemez river. The Sulphur springs deposit sulphur in considerable quantity as the name indicates—(see analysis of spring No. 11)—and their site was obtained as a mineral claim. They are owned by the Otero family and their value is now estimated at \$100,000.00.

Many years ago the Oteros erected a mill for the extraction of sulphur from the large sulphur deposits, but later heirs to the estate have let the mill lie idle for the past fifteen years and today the expensive machinery is rotting for lack of attention. Mr. Alfredo Otero, the present owner, states that the extraction of sulphur was discontinued because of the excessive freight rates, and also because of the fact that, as the diggings became deeper, the temperature increased to such a point that it was impossible for a man to work in the mine.

What was considered to be an average sample of the crude deposit in the old tunnel was analyzed quantitatively for free sulphur showing it to contain about 75% free sulphur.

FIELD OPERATIONS.

The plateau was visited in October, 1911, by a party of professors and students of the University of New Mexico. The party included Mr. J. A. Pynch, Associate Professor of Geology and State Geologist, Mr. J. D. Clark, Associate Professor of Chemistry, Mr.

A. O. Weese, Assistant Professor of Biology, and several students of the University, among them, Mr. E. V. Anspach. A very hasty examination of the topography of the district was made, nothing further being done at this time.

In October, 1912, Professor Clark and Mr. C. Kelly made a more extended visit to the district. During this visit the samples of waters, sinters, and gas, which were used in the analyses, were collected, temperatures of the waters of the springs taken, and a close examination of the external appearance of the springs was made. Note was also made of the clearness or turbidity of the waters, and the presence or absence of hydrogen sulphide. The test for the latter was merely by sense of smell.

The operations of collecting and preparing the samples for transportation were carried out as simply as possible. The water was bottled in glass-stoppered bottles, which were then sealed with sealing wax or paraffin. In every case care was taken to clean the receptacle thoroughly and to rinse, before bottling, with some of the water to be examined.

The difficulties in the way of collecting and transporting large quantities of water in a region comparatively inaccessible were such that the collection of large samples of water from any one spring was impossible. The size of the sample was necessarily small and varied from a half liter to one liter.

The thermometer used in taking the temperatures of the various springs was a Centigrade thermometer

which had been carefully standardized with a standard thermometer.

METHODS OF ANALYSIS.

Because of the limited time at our disposal for making this study we used the rapid methods of analysis described below taken largely from Water Supply Paper No. 236 of the United States Geological Survey. The author of the above paper states that with these methods one can estimate the principal acids and bases with moderate accuracy. We would advise anyone making a more thorough investigation of the waters we have studied to use the refined methods described in more technical works on water analysis. Among such works are, Bulletin 47 of the United States Geological Survey, and a bulletin of the Department of the Interior entitled, 'Analyses of the Waters of the Hot Springs of Arkansas, by J. K. Hayward, and Geological Sketch of Hot Springs, Arkansas, by Walter Harvey Weed.'

In each sample of water we determined:

Total dissolved solids

Silica

Ferric oxide (Fe_2O_3)

Aluminum oxide (Al_2O_3)

Calcium

Magnesium

Sodium

Potassium

Sulphates

Carbonates

Bicarbonates

Chlorine
Nitrates
Total acidity
Total iron
Hydrogen sulphide

Total suspended solids was also determined in one of the waters, viz., that from the Mud Geyser.

In the samples of gas collected from the Original Spring we determined:

Carbon dioxide
Methane
Hydrogen
Oxygen
Nitrogen

In the sinters we analysed qualitatively for the following:

Arsenic
Lithium
Phosphates
Borates

In addition to this we analysed quantitatively for sulphur in the mud of the Mud Geyser, since it gave evidence of containing an unusually large amount of that element in the free state.

METHODS OF ANALYSIS OF THE WATERS.

TOTAL DISSOLVED SOLIDS.

Total dissolved solids were regularly determined on 250 cubic centimeters of the filtered sample, which was evaporated to dryness on the water bath in a tared platinum dish, dried at about 180 degrees for one hour,

cooled and weighed. The residue was computed to parts per million of total dissolved solids.

The determination of dissolved solids is usually regarded as desirable, if for no other reason than to serve as a control of the summation of the determinations of the individual constituents; but the complexity of these waters and the relations of the combined salts are such that it is not possible to arrive at the same end by the determination of dissolved solids and the summation of the individual constituents. The action of free silica, which is an abundant constituent of the waters, is to set free during the process carbonic acid from the carbonates and boric acid from the borates; to magnify the tendency of the chlorides of calcium, magnesium, and lithium; to exchange chlorine for oxygen, and, if the temperatures be pushed sufficiently high, to dehydrate the silica and to volatilize sulphuric acid. Furthermore, the extent of such action is variable and indeterminate. There is obvious reason, therefore, for the difficulty which we experienced in obtaining results on the individual constituents whose sum would equal the total solids as determined above. In nearly all the waters under consideration the sum of individual constituents was considerably in excess of the total solids. This was due in part to the reasons given above and also to the fact that the ferrous iron, as well as the ferric iron, was calculated as ferric oxide, thereby introducing oxygen which was not present in the total solids.

SILICA.

The residue from the determination of total dissolved

solids, after being gently heated until the organic matter was carbonized or wholly destroyed, was moistened with hydrochloric acid (1:1) and the dish, covered with a watch glass, was heated on the water bath for a few minutes. After treatment with acid had been repeated, if necessary, the sides of the dish were thoroughly rubbed down, and the mass was evaporated to dryness. The residue was again treated with two or three cubic centimeters of the acid and some distilled water, was heated on the water bath, and was finally separated from the solution by filtration through ashless filter paper. The insoluble part was thoroughly washed with hot water containing hydrochloric acid, ignited in a tared platinum crucible, cooled and weighed. It was moistened with a few drops of sulphuric acid (specific gravity 1.84), and the silica was volatilized with hydrofluoric acid, after which the crucible was again ignited, cooled and weighed. The part volatilized by hydrofluoric acid was computed to parts per million of silica. The non-volatile residue was dissolved in hydrochloric acid and added to the filtrate from the silica.

IRON AND ALUMINIUM.

The iron in the filtrate from the determination of silica was oxidized by boiling the solution with a few drops of nitric acid (specific gravity 1.42). After a slight excess of ammonium hydrate had been added, the liquid was heated for a few minutes to precipitate the hydroxides of iron and aluminium, which were then removed by filtration and washed with hot water containing a little ammonium chloride. The precipitate

was dried, placed in a tared platinum crucible, ignited and weighed as combined oxides of iron and aluminium.

TOTAL IRON.

In several cases where the amount of iron and aluminium oxides was large, a determination of total iron was made. This was done by fusing the oxides of iron and aluminium with potassium hydrogen sulphate, and transferring the fused mass to a beaker containing sodium hydrate in solution, which precipitated the iron as ferric hydrate and retained the aluminium in solution as sodium aluminate. The precipitate was separated from the liquid by filtration, washed, dried, transferred to a tared platinum crucible, ignited and weighed as ferric oxide. From the weight of ferric oxide the amount of iron was calculated.

CALCIUM.

The filtrate from the determination of iron and aluminium was diluted to a definite volume, usually 100 cubic centimeters, and was divided into two equal parts. One part was used for the determination of calcium and magnesium and the other part for the determination of sulphates and alkalies. After the portion for the determination of calcium and magnesium had been heated to boiling in a beaker, it was made slightly alkaline with ammonium hydrate; ammonium oxalate in the form of hot five per cent aqueous solution was then added to it in sufficient amount to convert all the calcium and magnesium into oxalates. Ten cubic centimeters were usually added, but more was used if the figure for total solids indicated that this amount was not enough. The mixture was di-

gested not less than three hours in order to precipitate all the calcium and to dissolve the magnesium oxalate. The solution was filtered and the precipitate washed with hot water containing a little ammonia, no special care being taken to transfer all the calcium oxalate from the flask to the funnel. The flask in which the precipitation was made was then placed under the funnel, and while the precipitate was agitated by a stream of hot water from a wash bottle, dilute sulphuric acid (1 to 3) was poured on till the precipitate was completely decomposed and dissolved, after which the filter paper was thoroughly washed with hot water. If this operation is skillfully performed, the calcium precipitate is easily dissolved and twenty cubic centimeters of the dilute acid is amply sufficient for the purpose. The solution of calcium was diluted to about one hundred cubic centimeters with hot distilled water, brought to boiling, and titrated with N/20 potassium permanganate.

MAGNESIUM.

The filtrate from the calcium, having been made slightly acid with hydrochloric acid, was concentrated till the salts began to crystallize. An excess of a ten per cent solution of sodium ammonium phosphate was added, and the liquid was allowed to cool. Finally it was made distinctly alkaline with ammonium hydrate and set aside not less than six hours in order to insure complete precipitation of the magnesium. Two cubic centimeters of strong ammonia (specific gravity 0.90) was usually sufficient in a volume of fifty to seventy-five cubic centimeters. A large excess of ammonia is

distinctly disadvantageous. The precipitate was separated by filtration and was washed by decantation with water containing a little ammonia, till the excess of precipitant was removed. The precipitate in the beaker and on the paper was dissolved in five cubic centimeters of five per cent acetic acid and about forty cubic centimeters of hot water. Five cubic centimeters of a five per cent ammonium acetate solution was added and the solution was titrated with standard uranium solution, care being taken to boil the solution vigorously before noting the final end point, which is found by adding a drop of the liquid to a drop of half-saturated solution of potassium ferro-cyanide on a white porcelain plate.

It is important to have a constant amount of solution, as the end point varies somewhat with the volume. The quantity of phosphate that is titrated should be such that one to twenty cubic centimeters of uranium solution may be added.

SULPHATE RADICLE.

The usual gravimetric method was employed for the determination of sulphates. One-half the filtrate from the determination of iron was slightly acidulated with hydrochloric acid and was heated nearly to boiling. Excess of barium chloride in hot ten per cent solution was then added, after which the liquid was digested on the hot plate for at least thirty minutes. The precipitate of barium sulphate was removed by filtration, thoroughly washed with hot water, dried, ignited and weighed. The amount of sulphates as parts per million of SO_4 was computed from that weight.

SODIUM AND POTASSIUM.

The filtrate from the sulphate determination was treated with ammonia and ammonium carbonate and was filtered. The filtrate was evaporated to dryness on the water bath, heated to expel ammonium salts, and digested with a few cubic centimeters of distilled water. The filtrate from this operation was heated, and barium and calcium were precipitated with ammonium carbonate and were removed by filtration, after which the filtrate was evaporated to dryness and heated to expel ammonium salts. The residue was digested with four or five cubic centimeters of water, warmed, and treated again with ammonia and ammonium carbonate to remove traces of barium and calcium. The solution was then filtered into a small porcelain dish and evaporated to dryness. The residue was heated nearly to fusion and weighed. The alkaline chlorides in the dish were dissolved in a little water and were filtered through an ashless filter paper, which was then washed, ignited in the porcelain dish, and weighed. The difference in weights was calculated as sodium and potassium chlorides. The filtrate was evaporated to dryness and treated with eighty per cent alcohol, and platinic chloride. The precipitate of potassium platinic chloride was removed by filtration, washed with eighty per cent alcohol, and dissolved on the filter with warm water. The solution was evaporated to dryness in a tared platinum or porcelain dish and weighed as potassium platinic chloride. From the weight of the potassium double salt the parts per million of potassium were computed,

CARBONATE AND BICARBONATE RADICLES.

Estimates of the carbonate and bicarbonate radicles were made on the same fifty cubic centimeter sample of the water, which was filtered if necessary. Ten drops of phenolphthalein were added to the measured sample in a porcelain dish of convenient size and the sample was titrated with N/50 potassium acid sulphate solution. The number of cubic centimeters of acid used, multiplied by 24, equals parts per million of the carbonate radicle. Two drops of methyl orange were added to the same liquid and the titration was continued. The total amount of acid used, minus twice that required for the first end point equals that equivalent to the bicarbonate present. The latter figure, expressed in cubic centimeters and multiplied by 24.4 equals parts per million of the bicarbonate radicle.

CHLORINE.

The usual volumetric procedure was employed for the determination of chlorine. One hundred cubic centimeters of the sample were placed in a porcelain dish, one cubic centimeter of a five per cent potassium chromate solution was added and standard silver nitrate then added from a burette, till the first faint reddish tint appeared. The chlorine in parts per million was then computed.

In the acid waters it was necessary to neutralize with bicarbonate of soda before adding the potassium chromate, because the sulphuric acid of the water would form chromic acid with the chromate, thereby darkening the solution so much as to obliterate the end point of the determination.

NITRATES.

The phenolsulphonic acid method was used for the determination of nitrates. Fifty cubic centimeters of the clear water was evaporated to dryness in a porcelain dish on a water bath with a few drops of sodium carbonate solution. One cubic centimeter of phenolsulphonic acid was quickly and thoroughly rubbed over the residue in the dish, after which ten cubic centimeters of distilled water were added and the solution was stirred till it was thoroughly mixed. After enough ammonium hydrate to render the liquid alkaline had been added, the solution was transferred to a Nessler tube and was diluted to the mark with distilled water. The yellow color developed by the nitrates was compared with similar shades in Nessler tubes containing solutions of known amounts of potassium nitrate that had been treated with phenolsulphonic acid and ammonia. The results are reported as parts per million of the nitrate radicle.

Though this procedure is comparatively accurate for estimating the amount of nitrogen actually present as nitrates at the time of the test, it must be emphatically stated that the reported nitrate figures do not represent the amount of nitrogen present as nitrates in the waters when the samples were collected. Practical considerations made it impossible to perform the test until considerable time had elapsed after the samples had been collected, and though the value of the determination as an index of the condition of the waters at the time the samples were taken is probably not great, the amounts found may furnish some informa-

tion regarding the amount of organic matter that is present, and this feature is the excuse for the presentation of the nitrate figures in the analytical data.

TOTAL ACIDITY.

If the water under examination contained free mineral acid a convenient amount of the sample, filtered if necessary, was titrated with N/10 sodium carbonate in the presence of methyl orange indicator. If fifty cubic centimeters of the water is titrated, the number of cubic centimeters of N/10 alkali used, multiplied by 98, gives the result in parts per million of free sulphuric acid.

HYDROGEN SULPHIDE.

A measured quantity, say ten cubic centimeters, of N/10 arsenious acid solution was put into a 300 c. c. flask, and twenty cubic centimeters of the water added, well mixed, and sufficient hydrochloric acid added to produce a distinct acid reaction; this produces a precipitate of arsenic sulphide, and the liquid itself is colorless. The whole is then diluted to 300 cubic centimeters, filtered through a dry filter into a dry vessel, 100 cubic centimeters of the filtrate taken out and neutralized with sodium carbonate, then titrated with N/10 iodine and starch. The quantity of arsenious acid so found is deducted from the original ten cubic centimeters and the remainder multiplied by the requisite factor for hydrogen sulphide, which is reported as parts per million.

ANALYSIS OF THE SINTERS.

The analysis of the sinters was merely a qualitative

test for substances that would probably be present in too small quantity to be discovered in the small amounts of water which we were forced to use in the analysis.

Arsenic was tested for by means of the Marsh Apparatus, phosphates by the regular molybdate method of qualitative analysis, and lithium and boron tested for by means of an Adam Hilger best grade wavelength spectroscope.

ANALYSIS OF THE GAS.

The analysis of the gas collected from the "Original Spring," was made according to the methods given in Hempel's "Gas Analysis".

The carbon dioxide was absorbed by means of a potassium hydroxide solution. Oxygen was absorbed by means of sticks of yellow phosphorous. Air was then added to the remaining mixture of gases and the hydrogen was taken out by passing the mixture over heated palladinized asbestos, thus converting the hydrogen present into water. Methane was determined by exploding an aliquot portion of the gas and absorbing the carbon dioxide formed by passing it into potassium hydroxide solution. After the removal of the above constituents, the remainder of the gas present was assumed to be nitrogen.

The gas from this spring seemed to be a fair average of the gases evolved from the springs of the Jemez Hot Springs group and for this reason this gas was taken for the analysis. Although we were unable to detect any hydrogen sulphide in the gas by the sense of

smell, a small amount was undoubtedly present as shown by the fact that the white lead paint on the base of the summer house over the spring had been entirely blackened by the action of hydrogen sulphide. However, we did not analyse the gas for hydrogen sulphide content.

SULPHUR DETERMINATION IN MUD OF MUD GEYSER.

Because the mud in the Mud Geyser showed evidence of having a high free sulphur content, a quantitative determination of that element was made on the mud.

The mud was thoroughly dried and a weighed portion was put in an extraction shell, which was in turn placed in a Soxhlet extractor and the sulphur extracted by carbon disulphide. The carbon disulphide was then evaporated and the residue weighed as pure sulphur.

As a rough check on the above determination and also to determine the amount of sulphur present in the form of insoluble sulphides, another weighed portion of the dried mud was placed on a filter and washed with hot water until free from soluble sulphides and sulphates. The residue on the filter was then washed into a flask, about 100 cubic centimeters of nitric acid added, and the mixture boiled until the evolution of nitrogen peroxide fumes was faint. It was then filtered and the filtrate heated almost to boiling. A hot aqueous solution of barium chloride was then added and the mixture digested on the hot plate for half an hour. The precipitate of barium sulphate was then filtered off,

washed with hot water, ignited and weighed. The percentage of sulphur was then calculated from this weight.

DESCRIPTION AND LOCATION OF THE SPRINGS.

Spring No. 1. This is the so-called Soda Spring at Jemez Hot Springs, New Mexico. The vent, which lies about the center of the town, is in the river bottom, the waters coming up through the river-bed gravels. A green scum of organic matter fringes the vent and a deposit of the color of ferric hydroxide lines it inside. The pool is about one foot in diameter. A considerable quantity of gas is being evolved. Several larval worms about three inches long are in the water just outside the pool.

Spring No. 2. This spring is known as the Original Spring. It lies about thirty yards northeast of the Soda Spring. The pool, into which the spring flows, is about seven feet in diameter and three feet deep. It is lined with a deposit of the color of ferric hydroxide and a green scum of organic matter fringes it at the surface of the water. A large quantity of gas bubbles from the spring. The pool is covered by a small summer house and pipes lead some of the water to the bath house about fifty feet to the south.

Spring No. 3. This is the Iron Spring, so-called because of the color of the deposit, this color being that of iron rust. The color is not due to iron oxide but is due to a red algal growth. The spring is situated about fifty feet southeast of the Soda Spring. The deposit

does not form a sinter but remains soft and flaky. The banks of the small stream flowing from the spring are covered with a dark green deposit of organic matter at the edge of the water. A platform is built over the spring with a cement box in the center into which the spring flows.

Spring No. 6. This spring lies on top of and to the extreme west end of the Soda Dam. The pool of the spring is about one and one-half feet long by one foot wide and six inches deep. The water is strongly charged with gas having a faint odor of hydrogen sulphide. The bottom of the pool is covered with a dark green lining of organic matter.

Spring No. 8. The spring bubbles up through numerous vents into a submerged bottomless bath-tub in the Main Bath House at Sulphur Springs, New Mexico, about fifteen miles north of Jemez Hot Springs. The water, which is very turbid, deposits mud in the bottom of the tub, and the gas from the spring, which has a strong odor of hydrogen sulphide, deposits sulphur crystals on the sides of the bath-tub and walls of the house.

Spring No. 9. This is known as the Sour Spring. It lies a short distance to the north of the Main Bath House at Sulphur Springs. The water tastes strongly of sulphuric acid. The pool over the vent is about a foot square and one foot deep. A small amount of gas accompanies the water. Solfataras within twenty feet and to the south of the spring are blowing steam and gas, which has a temperature of eighty-nine degrees Centigrade, or about two degrees less than the boiling

point of water at this altitude. Within twenty-five feet of the Sour Spring are vents, said to be the openings of an extinct geyser. Pine logs near the spring are badly charred by the sulphuric acid in the water.

Spring No. 10. The Alum Spring, as it is called, has a taste of strong alum water. It lies in the bed of an arroyo about three hundred feet to the east of the Sour Spring. The pool is about the same size as that of the Sour Spring, but the vents are much larger, being three inches in diameter. A large amount of gas comes up through the water in the pool and also through the sand in the bed of an arroyo around the spring.

Spring No. 11. The Mud Geyser would hardly be called a spring because no water flows out of it. This geyser lies almost due north of the Alum Spring. The pool of the geyser, which is about seven feet in diameter and three feet deep, seems to maintain a constant level of water, except when an excess of rain-water causes it to overflow. Even the hot, dry days of summer do not evaporate the water sufficiently to make much of a change in the level of the water. An exceedingly large amount of gas comes up through the water from a great many vents in the bottom of the pool. The odor of hydrogen sulphide is very strong. The escaping gas strongly agitates the surface of the water, giving it the appearance of a large vessel of violently boiling water. The water, or mud as it may be called, has a total of 94,500 parts per million of suspended solids. (See analysis of sinter No. 11.)

Spring No. 12. This quiet little spring, known as

the Seltzer Spring, bubbles up into a submerged barrel about two hundred yards up the arroyo from the Mud Geyser. The water resembles seltzer water, both in its taste and in its effect on the human system. A small quantity of gas, having a very faint odor of hydrogen sulphide, comes to the surface. This gas has deposited a small amount of sulphur on the rocks surrounding and above the barrel.

Spring No. 13. This spring is called the Electric Spring because of the fact, residents say, that the bubbles of gas in it give a sharp pain, resembling a shock from an electric current, to an open sore or fresh cut in the flesh. This spring flows into a large bath-tub twelve feet long, four feet wide and three feet deep, made of logs, which are charred by the highly acid waters of the spring. The deposit of the spring is very light and flocculent and of a light yellow color. The vents are very minute, but are numerous enough to cause a small stream of water to flow from the tub. The spring is situated about fifty yards south of the Otero Sulphur Mill.

Spring No. 14. The water comes from numerous vents inside of a submerged bottomless wooden bath-tub in the Ladies' Bath House at Sulphur Springs. Mud settles from the water and sulphur crystals form on the sides of the tub. A large amount of gas accompanies the water and gives a strong odor of hydrogen sulphide.

Samples of the sinters numbers 1, 2, 6 and 8 were taken from the deposits formed around the edges of the pools of the springs of the corresponding numbers;

samples numbers 11, 13 and 14 were samples of the mud deposited in the bottom of the pools from the springs corresponding to the same numbers; the other three samples were taken as follows:

Sinter No. 4. Sample taken from a deposit formed around a spring of multiple vents in the bed of the river at a distance of about one hundred feet below the Soda Dam. The mound on which the springs occur, is completely surrounded by the flowing water of the river. One of the vents throws a stream of water at an angle of approximately thirty degrees with the horizontal for a distance of about six feet.

Sinter No. 5. This sample was taken from the deposit around a small pool of water along the crack in the middle of the top of the Soda Dam. Light green organic matter lines the pool.

Sinter No. 7. This was taken from around the pool of the spring at the extreme east end of the dam. This spring is at present forming, by its deposits, a large dome of the dam directly over the river. The bottom of the pool of the spring is coated with very dark green organic matter.

TABLE OF TEMPERATURES OF THE SPRINGS.

Number	Date	Degrees Centi- grade	Degrees Fahren- heit
1.....	Oct. 11, 1912	68.5	155.3
2.....	Oct. 11, 1912	68.0	154.5
3.....	Oct. 11, 1912	48.8	119.8
4.....	Oct. 11, 1912	46.5	115.7
5.....	Oct. 11, 1912	23.0	73.6
6.....	Oct. 11, 1912	40.0	104.0
7.....	Oct. 11, 1912	43.5	110.3
8.....	Oct. 11, 1912	68.5	155.3
8.....	Oct. 12, 1912	41.0	105.8
9.....	Oct. 12, 1912	44.0	112.2
10.....	Oct. 12, 1912	15.2	59.4
11.....	Oct. 12, 1912	38.0	100.4
11.....	Oct. 12, 1912	31.0	87.8
12.....	Oct. 12, 1912	10.4	50.7
13.....	Oct. 12, 1912	37.1	98.8
14.....	Oct. 12, 1912	75.0	167.0
14.....	Oct. 12, 1912	70.0	158.0

Where two temperatures are shown for one spring, the first temperature is that found in the mud in the bottom of the pool, and the second that found in the water of the pool.

ANALYSIS OF THE WATER OF SPRING NO. 1,
SODA SPRING, JEMEZ SPRINGS, N. M.
Analysed by Prof. J. D. Clark.

Constituents	Parts per Million	Per cent of total material in solution
SiO ₂	82.8	3.79
Fe ₂ O ₃ } Al ₂ O ₃ }	6.0	.27
Ca	136.8	6.25
Mg	6.1	.28
Na	538.6	24.63
K	71.9	3.24
SO ₄	61.6	2.82
CO ₃	0.0	0.00
HCO ₃	503.6	23.07
Cl	779.8	35.65
NO ₃	0.0	0.00
Acidity	0.0	0.00
H ₂ S	Trace	....
	<hr/>	<hr/>
	2187.2	100.00
Total Solids, heated one hour at 180°C..	2143.2	

The qualitative analysis of the sinter from around the spring showed the following to be present:

Arsenic Lithium Phosphates
and also showed the absence of borates.

ANALYSIS OF THE WATER OF SPRING No. 2,
ORIGINAL SPRING, JEMEZ SPRINGS, N. M.
Analysed by Mr. E. V. Anspach.

Constituents	Parts per Million	Per cent of total material in solution
SiO ₂	88.0	3.89
Fe ₂ O ₃ } Al ₂ O ₃ }	14.0	.61
Ca	124.0	5.48
Mg	10.1	.44
Na	408.2	18.08
K	62.6	2.76
SO ₄	54.4	2.40
CO ₃	0.0	0.00
HCO ₃	705.2	31.16
Cl	796.0	35.18
NO ₃	0.0	0.00
Acidity	0.0	0.00
H ₂ S	Trace	.....
	<hr/>	<hr/>
	2262.5	100.00
Total Solids, heated one hour at 180°C..	2131.6	

The qualitative analysis of the sinter from around the pool of the spring showed the presence of Arsenic, Lithium, and the phosphate radicle, and also showed the absence of borates.

The analysis of the gas gave the following results:

Carbon Dioxide	91.0%
Oxygen	.6
Hydrogen	.8
Methane	2.4
Nitrogen (Remainder)	5.2
	<hr/>
	100.0

ANALYSIS OF THE WATER OF SPRING NO. 3,
IRON SPRING, JEMEZ SPRINGS, N. M.
Analysed by Mr. Clyde Kelly.

Constituents	Parts per Million	Per cent of total material in solution
SiO ₂	105.2	4.47
Fe ₂ O ₃ {	4.8	.20
Al ₂ O ₃ {		
Ca	152.0	6.45
Mg	5.8	.25
Na	578.9	24.59
K	68.6	2.91
SO ₄	70.4	2.99
CO ₃	0.0	0.00
HCO ₃	500.2	21.25
Cl	868.7	36.89
NO ₃	Trace	0.00
Acidity	0.0	0.00
H ₂ S	Trace	0.00
	<hr/>	<hr/>
	2354.6	100.00
Total Solids, heated one hour at 180°C..	2327.6	

No sinter was formed around this spring.

ANALYSIS OF THE WATER FROM SPRING NO. 6,
 SPRING ON WEST END OF THE SODA DAM.

Analysed by Mr. Clyde Kelly.

Constituents	Parts per Million	Per cent of total material in solution
SiO ₂	58.0	1.21
Fe ₂ O ₃ }	105.2	2.20
Al ₂ O ₃ }		
Ca	292.8	6.12
Mg	0.3	0.01
Na	1069.9	22.38
K	98.5	2.06
SO ₄	56.6	1.18
CO ₃	0.0	0.00
HCO ₃	1556.7	32.56
Cl	1543.4	32.28
NO ₃	Trace	0.00
Acidity	0.0	0.00
H ₂ S	Trace	0.00
	4781.4	100.00
Total Solids, heated one hour at 180°C..	4085.6	

The analysis of the sinter from around this spring showed the presence of arsenic, lithium and the phosphate radicle, and the absence of borates.

ANALYSIS OF THE WATER FROM SPRING No. 8,
 MAIN BATH HOUSE, SULPHUR SPRINGS, N. M.
 Analysed by Mr. E. V. Anspach.

Constituents	Parts per Million	Per cent of total material in solution
SiO ₂	264.0	9.28
Fe ₂ O ₃ } Al ₂ O ₃ }	294.8	10.36
Ca	128.8	4.52
Mg	3.9	0.14
Na	376.8	13.24
K	48.0	1.69
SO ₄	1468.8	51.61
CO ₃	0.0	0.00
HCO ₃	0.0	0.00
Cl	210.0	7.37
NO ₃	0.0	0.00
Acidity.	254.8	....
H ₂ S	51.1	1.79
Fe	10.0	....
	*2846.2	100.00
Total Solids, heated one hour at 180°C..	2849.6	

* Acidity and total Iron not included in total.

Qualitative tests on the mud from this spring showed arsenic, lithium, and the phosphate and borate radicles to be absent.

ANALYSIS OF THE WATER FROM SPRING NO. 9,
SOUR SPRING, SULPHUR SPRINGS, N. M.

Analysed by Mr. Clyde Kelly.

Constituents	Parts per Million	Per cent of total material in solution
SiO ₂	227.6	10.21
Fe ₂ O ₃ } Al ₂ O ₃ }	172.0	7.72
Ca	174.4	7.83
Mg	8.7	0.39
Na	44.7	2.01
K	12.2	0.55
SO ₄	1574.9	70.68
CO ₃	0.0	0.00
HCO ₃	0.0	0.00
Cl	12.1	0.54
NO ₃	1.5	0.07
Acidity	627.2	....
H ₂ S	Trace	0.00
	*2228.1	100.00
Total Solids, heated one hour at 180°C..	2218.8	

* Acidity not included in total.

No sinter was formed around this spring.

ANALYSIS OF THE WATER FROM SPRING NO. 10.
THE ALUM SPRING, SULPHUR SPRINGS, N. M.
Analysed by Mr. E. V. Anspach.

Constituents	Parts per Million	Per cent of total material in solution
SiO ₂	123.2	2.48
Fe ₂ O ₃ } Al ₂ O ₃ }	931.2	18.71
Ca	354.0	7.11
Mg	9.6	0.19
Na	580.0	11.65
K	134.0	2.69
SO ₄	2837.2	56.99
CO ₃	0.0	0.00
HCO ₃	0.0	0.00
Cl	8.1	0.16
NO ₃	1.0	0.02
Acidity	627.2	....
H ₂ S	Trace	....
Fe	212.8	....
	*4978.3	100.00
Total Solids, heated one hour at 180°C..	5252.8	

* Acidity and total iron not included in total.

No sinter around this spring and no deposit formed, therefore none available to determine if arsenic, lithium, and the phosphate and the borate radicles were present.

ANALYSIS OF THE WATER FROM SPRING NO. 11,
MUD GEYSER, SULPHUR SPRINGS, N. M.

Analysed by Mr. Clyde Kelly.

Constituents	Parts per Million	Per cent of total material in solution
SiO ₂	356.0	7.53
Fe ₂ O ₃ }	518.0	10.98
Al ₂ O ₃ }		
Ca	15.2	0.32
Mg	18.6	0.39
Na	7.9	0.16
K	32.9	0.69
SO ₄	3707.0	78.41
CO ₃	0.0	0.00
HCO ₃	0.0	0.00
Cl	8.1	0.17
NO ₃	0.0	0.00
Acidity	2724.4	.....
H ₂ S	63.9	1.35
Fe	319.8	.....
	*4727.6	100.00
Total Solids not determined.		

* Acidity and total iron not included in total.

Qualitative tests on the mud in the geyser showed absence of arsenic, lithium, phosphate and borate radicles.

Because of the high acidity of the water total solids were not determined on this sample.

ANALYSIS OF THE WATER FROM SPRING NO. 12,
 SELTZER SPRING, SULPHUR SPRINGS, N. M.

Analysed by Mr. Clyde Kelly.

Constituents	Parts per Million	Per cent of total material in solution
SiO ₂	35.2	3.14
Fe ₂ O ₃ }	10.4	0.93
Al ₂ O ₃ }		
Ca	220.0	19.65
Mg	4.8	0.43
Na	22.4	2.00
K	15.5	1.39
SO ₄	589.4	52.65
CO ₃	0.0	0.00
HCO ₃	212.3	18.97
Cl	8.1	0.72
NO ₃	1.3	0.12
Acidity	0.0	0.00
H ₂ S	Trace	.....
	1119.4	100.00
Total Solids; heated one hour at 180°C..	972.0	

No sinter was formed around this spring; therefore none available for determining the presence or absence of arsenic, lithium, and phosphate and borate radicles.

ANALYSIS OF THE WATER FROM SPRING NO. 13.
ELECTRIC SPRING, SULPHUR SPRINGS, N. M.
Analysed by Mr. E. V. Anspach.

Constituents	Parts per Million	Per cent of total material in solution
SiO ₂	186.0	3.45
Fe ₂ O ₃ } Al ₂ O ₃ }	953.6	17.69
Ca	48.0	0.89
Mg	1.0	0.02
Na	47.8	0.89
K	80.0	1.48
SO ₄	4061.6	75.33
CO ₃	0.0	0.00
HCO ₃	0.0	0.00
Cl	12.1	0.22
NO ₃	1.5	0.03
Acidity	2587.2	.....
H ₂ S	Trace	.....
Fe	500.1	.....
	*5391.6	100.00
Total Solids, heated one hour at 110°C..	5220.0	

* Acidity and total iron not included in total.

Qualitative tests on the deposit of the Spring showed the presence of arsenic, and the absence of lithium, and the phosphate and borate radicles.

ANALYSIS OF THE WATER FROM SPRING NO. 14,
LADIES' BATH HOUSE, SULPHUR SPRINGS, N. M.
Analysed by Mr. E. V. Anspach.

Constituents	Parts per Million	Per cent of total material in solution
SiO ₂	148.0	2.02
Fe ₂ O ₃ {	1174.0	15.97
Al ₂ O ₃ }		
Ca	141.3	1.92
Mg	7.1	0.10
Na	780.8	10.62
K	34.7	0.47
SO ₄	4989.4	67.87
CO ₃	0.0	0.00
HCO ₃	0.0	0.00
Cl	8.1	0.11
NO ₃	0.0	0.00
Acidity	1156.4	....
H ₂ S	67.7	0.92
Fe	206.3	....
	*8565.8	100.00
Total Solids, heated one hour at 110°C..	7112.5	....

* Acidity and total iron not included in total.

Qualitative analysis of the mud from the bottom of the bath-tub showed the presence of arsenic, and the absence of lithium; also the presence of the phosphate radicle and the absence of the borate radicle.

THE SOURCE OF HEAT

In comparing the temperatures of the different groups of springs, we find that those situated nearest Mt. Pelado have the greatest degree of heat, while those at the greatest distance from this mountain are either cold or nearly so. In other words, the temperature decreases as the distance from Mt. Pelado increases. Mt. Pelado, as we know, was once part of the rim of a great volcano. It is evident from this that the heat producing agent is near the locality of this volcano. We believe that there still exists, deep underground, a large mass of heated rock, with which descending waters come in contact.

The composition of the gas we analysed shows that it contains atmospheric air as well as carbon dioxide. This would indicate that a part of the water had been near the air shortly before it came into contact with the source of heat. Deep-seated waters coming into contact with heated rock probably ascend toward the surface as vapors. During their ascent they probably meet cold spring waters which are heated by them. It is interesting to note that hot springs have never been found to exist in any localities except where igneous rocks are present. This, in itself, would seem sufficient to contradict any hypothesis attempting to assign the cause of heat to chemical action alone.

CHEMISTRY INVOLVED.

From the foregoing analyses we can see that the springs we have analysed may be divided into the fol-

lowing general classes with respect to their negative or acid radicles:

- I. Sulphato-carbonate waters SO_4 and CO_3 both abundant.
- II. Triple waters, containing chlorides, sulphates, and carbonates, all in notable amounts.
- III. Acid waters, containing free acids. Acid chiefly sulphuric.

The different classes will be considered in the order mentioned above.

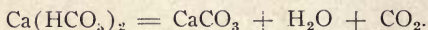
The method of formation of the different waters is merely a theory and not a proven fact; and the following are the theories probably best fitted to the formation of the waters of the Jemez Plateau, since the strata of the region make such theories possible.

It is evident that the waters of the sulphate-carbonate class have primarily come up through the Carboniferous strata, and, since sodium carbonate and calcium sulphate are readily soluble in water, have dissolved a large quantity of these alkalis and carried them along in solution. Further on in its course this alkaline water has probably come in contact with some form of granite, such as rhyolite, and dissolved some of the silica. This silica in solution will then act on a carbonate producing a silicate and freeing carbon dioxide, as shown by the equation.



This would partly account for the carbon dioxide coming from the springs, though it is not probable

that all of the carbon dioxide issuing from the springs is formed by this reaction alone. Possibly some of this gas is formed by the decomposing of carbonate rocks by highly heated steam formed by water coming in contact with heated rocks deep under the surface of the earth. The carbon dioxide may also be obtained from the bicarbonates breaking down as, for example,



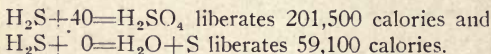
TRIPLE WATERS.

The triple waters have probably been formed exactly as have been the sulphate-carbonate waters, with the one exception of having come in contact with a strata of calcium or sodium chloride.

ACID WATERS.

The formation of sulphuric acid in the acid mineral waters has been well explained by Mr. G. F. Becker in Monograph XIII of the U. S. Geological Survey, pp. 254-55:

“The formation of sulphur and sulphuric acid from hydrosulphuric acid by oxidation is one of the most familiar facts of chemical geology and of experimental chemistry. The relations of the two processes are readily seen from a thermo-chemical standpoint, for the reaction



Hence if oxygen is present in excess, as it is at the surface of sulphur springs and in porous sinters

partially saturated with solutions of hydrosulphuric acid, this will simply be oxidized to sulphuric acid. But if oxygen is deficient, as it must be a short distance from the surface, a single atom of oxygen by combining with $\frac{1}{4}\text{H}_2\text{S}$ to $\frac{1}{4}\text{H}_2\text{SO}_4$ would produce only 50,375 calories, or 8,725 less than it sets free according to the second of the above reactions. Assuming, therefore, that the two reactions are accomplished in nearly the same time, sulphuric acid will be formed at the surface of such a region and free sulphur below the surface. This is in correspondence with observations at sulphur springs the world over and with laboratory experiments. When sulphides of the alkalies are present the reactions are more complex, but sulphur is also separated while hyposulphites are formed. There is nothing strange or novel in the occurrence of sulphur under the conditions present—”.

It is also to be borne in mind that aqueous sulphuric acid will decompose chlorides, with liberation of hydrochloric acid, and this reaction also probably occurs. The acidity of a mineral water, then, may be due to a variety of causes, which operate under varying conditions of material and temperature.

CHANGES IN WATERS.

The following, although not enclosed in quotation marks, is taken directly from Bulletin 491 of the U. S. Geological survey.

When the water of a spring emerges into the open air it begins to undergo changes. It may flow into

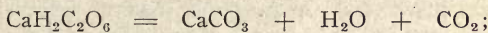
other waters, and so lose its individuality; it may simply evaporate, leaving a saline residue; it may react upon adjacent material and so produce new substances; or, by cooling, it may deposit some one or more of its constituents. The first of these contingencies admits of no systematic discussion; the third will be considered in the next chapter; the others can receive attention now.

Alteration by loss of gaseous contents is observed in two important groups—the sulphur waters and those containing an excess of carbonic acid. Hydrogen sulphide partly escapes into the atmosphere without immediate change, and part of it is oxidized, with deposition of sulphur and the formation of thiosulphates and finally sulphates, which remain in solution. Deposits of finely divided sulphur are common around those springs which emit hydrogen sulphide, but they frequently contain other substances, such as silica, calcium carbonate, and ochreous matter. Since, however, the sulphur is a product of partial oxidation, this change comes more appropriately under the heading of reaction with adjacent material, the latter in this case, being oxygen derived from the air. The hydrogen sulphide itself may be generated by the action of acid upon other sulphides, but it is more commonly produced by the reduction of sulphates through the agency of organic matter, and the subsequent decomposition of the resultant alkaline compounds by carbonic acid. The last reaction, however, is reversible. Carbon dioxide decomposes solutions of calcium hydrosulphide; but, on the other hand, hydrogen sulphide can partly decom-

pose solutions of calcium carbonate. Bicarbonates and sulphides, therefore, can co-exist in mineral waters in a state of unstable equilibrium.

CALCAREOUS SINTER.

With carbonated waters the changes due to escape of gas are more conspicuous, at least when calcium, magnesium or iron happen to be the important basic ions. When the "bicarbonic" ion HCO_3 breaks up, losing carbon dioxide to the atmosphere, the normal calcium or magnesium carbonate is formed and, being insoluble, is precipitated. If we assume calcium bicarbonate as existent in solution, the reaction is as follows:



but the change is modified by other substances which may be present, and so the product is rarely pure, nor is the precipitation absolutely complete. Calcareous sinter, tufa, or travertine is thus produced, and in many localities it is an important deposit. The carbonate waters of the Yellowstone Park, for example, form large bodies of this character, and many analyses of it have been made.

The commonest companion of calcium carbonate in sinter is magnesium carbonate, which is rarely, if ever, absent. The presence of magnesium salts in a water favors the deposition of calcium carbonate in the form of aragonite. Calcite, however, is much more common in sinters than aragonite. In rare instances fluorite is deposited. Silica and ferric hydroxide are also frequent contaminations of tufas. In short, the calcium

carbonate precipitated from natural waters may carry down with it a great variety of impurities, which depend upon the character of the spring.

OCHEROUS DEPOSITS.

When ferrous ions are present in a carbonate water, loss of carbonic acid is followed or accompanied by oxidation, and the precipitated material is an ocherous ferric hydroxide. Around chalybeate springs these deposits of iron rust are always noticeable. With substances of this character calcium and magnesium carbonates are often thrown down, and also silica, so that the ochers from iron springs vary much in composition. Between an ocher and a calcareous sinter every intermediate mixture may occur. Sometimes when sulphates have been reduced by organic matter sulphides of iron are deposited.

SILICEOUS DEPOSITS.

Siliceous deposits are formed by all waters containing silica, but are commonly so small as to be inconspicuous. The silica then appears as an impurity in something else. From hot springs, however, which often contain silica in large quantities, great bodies of sinter are produced, and this has a composition approaching that of opal. Mineralogically, siliceous sinter is classed as a variety of opal, for it consists mainly of hydrated silica with variable impurities.

When a water has become sufficiently concentrated to begin the deposition of solid matter, every change in concentration or temperature introduces a new set of conditions which determine the nature of the com-

pounds to be formed. It is clear from the nature of the products thus far considered, that in a complex water several reactions may take place simultaneously, a number of substances being thrown down at the same time. If water carrying much iron and much calcium loses hydrogen sulphide and carbonic acid, then ferric hydroxide, calcium carbonate, and sulphur will be deposited together, each change being independent of the others. In such cases the complexity of reaction is apparent only, and not real. The reactions are all simple and easily understood. When salts are formed by evaporation of a water, the interpretation of the phenomena is more difficult.

REACTIONS WITH ADJACENT MATERIAL.

The reactions of natural waters in contact with adjacent materials are of many different kinds. We have already seen how oxygen from the atmosphere may convert ferrous into ferric compounds and sulphides into sulphates, but reducing agents also must be taken into account. The sulphates of a water, by accession of organic matter, can be partly or entirely reduced to sulphides, and carbonic acid, acting upon the latter, may expel sulphureted hydrogen and produce carbonates. By reaction of that kind a water can undergo a complete change of type and pass from one class into another.

Acid waters, especially when hot, act vigorously on the substances with which they come in contact, producing soluble chlorides or sulphates according to their character. Hydrochloric acid forms the one set

of salts, sulphuric acid the other. The extent of the reactions will of course depend upon the kind of material attacked, for some minerals and rocks are much more soluble than others. The carbonate rocks are naturally the most attackable, but no rock is entirely exempt from changes of this order. When we remember that even pure and cold water exerts a solvent action upon many silicates, we can see how violently corrosive a hot, acid, volcanic water must be. Whenever waters of this class occur the surrounding rocks are more or less decomposed, calcium, magnesium, alkalis, and iron being dissolved out, while silica and hydrous aluminum silicates remain behind. As the water cools and as the acid becomes neutralized its activity decreases, and its peculiar characteristics gradually disappear. An ordinary saline or astringent water is produced by these changes, which take place most rapidly when the active solutions are concentrated and hot, and more slowly in proportion as they are diluted or cooled.

Waters containing free sulphuric or hydrochloric acid are, however, relatively rare, and their geological importance is small compared with that of carbonated solutions. Meteoric waters carrying free carbonic acid are probably the most powerful agents in the solution of rocks, although their chemical activity is neither violent nor rapid. Being continually replenished from the storehouse of the atmosphere, their work goes on unceasingly over a large portion of our globe. The calcium which they extract from rocks is carried by rivers to the sea, and is finally deposited in the form of

limestones. Springs and underground waters charged with carbonic acid exert the same solvent action, but locally and in different degree. Many springs, such as the Jemez springs are so heavily loaded with carbonic acid that they effervesce when issuing into the air, and such waters are peculiarly potent in effecting the solution of limestones. By percolating waters of this class limestone caverns are made, and part of the substance dissolved is redeposited as stalactite or stalagmite. In reactions of this kind the general character of a water is not changed; it may be a calcium carbonate water throughout its course, varying only in gaseous content and in concentration, and its chemical effectiveness is shown by its work as a carrier in transporting from one point to another the material that it has dissolved.

Alkaline waters, especially thermal waters of the sodium carbonate class, are also active solvents of mineral substances. Their tendency, however, is opposite to that of the acid waters, for they dissolve silica rather than bases, and act as precipitants for magnesia and lime. When solutions of calcium sulphate and sodium carbonate are commingled, calcium carbonate is thrown down and an equivalent amount of sodium sulphate remains dissolved. Since natural waters are rarely, if ever, chemically equivalent, reactions of this sort between them are necessarily incomplete, and the blended solutions will contain one group of ions in excess over the other. Thus a water of mixed type is produced, but the mixture is not an average of the two solutions, for part of their original load has been removed. This is a simple case of reaction, but it may

be complicated in various ways, and even reversed. For instance, a solution of sodium sulphate in presence of free carbonic acid will dissolve calcium carbonate, forming sodium bicarbonate and a precipitate of gypsum. Mr. E. W. Hilgard, in the *American Journal of Science*, 4th Ser., Vol. 2, 1896, p. 100, has investigated this transformation, and regards it as the principal source of alkaline carbonate solutions in nature. Furthermore, mineral substances with which alkaline waters come in contact may be profoundly modified.

Many mineral springs contain organic matter, presumably in the form of the so-called humus acids, but the influence exerted by these substances is more pronounced in swamp and river waters. Their supposed solvent action upon rocks and soils has already been noticed, as well as their alleged efficiency in retaining silica in solution.

Furthermore, iron and alumina may be removed from sulphate or chloride waters by the action of limestones. If the iron is in the ferrous state, it must first be oxidized to the ferric condition. Then, by means of calcium carbonate, both of the bases named can be precipitated, either as hydroxides or as basic sulphates. Insoluble compounds of the latter class are often formed from natural waters, and many mineral species are of that character. It is quite probable that limestone is also effective in removing other heavy metals from their solutions; copper, for example, is certainly thrown down, but these reactions need to be more fully investigated.

Finally, the character of a water may be greatly changed by simple percolation through the soil. That potassium is thus removed from natural waters has long been known. Hydrous aluminium silicates may be the effective absorbents, or, in the case of phosphoric acid, the hydroxides of aluminium and iron. After potassium and ammonium, Van Bemmelen finds that magnesium is most readily absorbed, then sodium, and calcium least of all. It is clear, however, that the nature of the soil must be taken into account. A sandy soil or an impervious clay would be less effective in removing saline substances from water than a loose loam rich in hydrous basic compounds. The fact that substances are taken from waters by soils is certain, but the extent of the absorption depends upon local conditions. It is also certain that potassium, rather than sodium, is thus withdrawn from aqueous circulation.

A careful consideration of all the evidence concerning mineral springs will show that it is exceedingly difficult to generalize on relations between the composition of a water and its geological history. Reactions which take place deep within the earth can not easily be traced, especially as a water may undergo various modifications before it reaches different sources—either a direct mixture or a solution from which ingredients have been removed—and it is only in specific cases that a simple interpretation of the phenomena can be found. The water that rises from a salt bed or from gypsum is easily understood, and so also is one which carries sulphates derived from pyritiferous shales. We can see that a water from granite must differ greatly

from one issuing out of limestone. Many irregularities can be traced, but no general principle can be deduced from them.

Various attempts have been made to correlate the composition of waters with the geological horizons from which they flow. For spring waters such attempts are of little value, because two springs, side by side, may be widely different. Artesian waters of common origin often show a family likeness to one another, especially in their minor constituents, one group being always calciferous, another relatively rich in bromine, and so on. But no law can be framed to cover even these regularities, for the exceptional waters are too numerous and too confusing. That waters from sedimentary rocks are, as a rule, more concentrated and perhaps more complex than those from the older crystalline formations is doubtless true; but beyond that it is hardly safe to generalize.

THERMAL SPRINGS AND VOLCANISM.

When a crystalline rock, like granite, is heated to redness in vacuo, water and gases, the latter identical in character with the volcanic gases, are given off. For instance, to cite the least significant example, 1 cubic kilometer of granite can yield from 25 to 30 millions of metric tons of water, which at $1,100^{\circ}$ would form 160,000,000,000 cubic meters of steam. In addition to this enormous volume of vapor 28,000,000,000 cubic meters of other gases would be emitted. Suppose now that by fissuring and subsidence in the lithosphere such a mass of rock were carried down to a depth of 25,000 to 30,000 meters. It would then be in

the heated region, and the evolution of vapors under great pressure would occur. To some such changes Gautier ascribes the phenomena of volcanism, with all its development of solfataras and fumaroles. Ordinary thermal springs may be formed by the same process, operating, perhaps, less violently, and originate, so to speak, from a sort of distillation of the combined water contained in the depressed masses of rock.

And yet, notwithstanding all that has been written on the subject, the controversy over the genesis of hot springs is not closed. What is the origin of the carbon dioxide with which so many mineral waters are heavily charged? In some instances, doubtless, it is derived from the decomposition of limestones, but in others this explanation cannot suffice. Here and there it may be, to use Suess's expression, "juvenile," and evidence of the deep-seated origin of the spring. Again, whence comes the sodium chloride of waters that flow from sources where it could not have been previously laid down? These questions, and others like them, still await satisfactory answers. With mere suppositions, however, plausible they may seem, we cannot be content.

A word in conclusion on the radioactivity of spring waters. A very large number of such waters possess this property, but no distinction between vadose and juvenile waters can be based upon the observations. Waters of both classes are radioactive, but the phenomenon is perhaps most common among waters of volcanic origin, or at least among thermal springs.

CONCLUSION.

As our title states, this investigation has been of merely a preliminary nature. We have examined the waters of only a few of the largest springs of the groups now being used by white men. We believe these springs to be typical of the groups in which they are located, however, and a study of other springs of the same groups would probably furnish nothing more than additional data of a similar nature. A more extended study of the waters should include an investigation of many of the springs neglected by us, however, for, although no new conditions may be discovered, the data obtained would be an additional check, and would also give more force to the conclusions drawn.

The other groups mentioned in the chapter on "The Springs," should also be given attention in an exhaustive study of the district. These springs, although of no importance commercially at present, could not be ignored by the scientist who seeks to unveil the geochemical secrets of the region.

As we have intimated elsewhere in this paper, the most accurate methods of water analysis available should be employed if the time at the disposal of the investigator permits. In many instances, larger quantities of water than we were able to use should be taken for the determinations. From the analysis of the sinters we have shown several constituents, which we did not determine in the waters, to be present, in small quantities, at least.

The gas we collected and analysed seemed to be a typical example of all that issuing from the springs of the Jemez Hot Springs group. Analyses of the gases of other groups should also be made. Certain of the elements of the helium group may be present in traces.

In his excellent booklet on the "Analyses of the Waters of the Hot Springs of Arkansas," Mr. Haywood states that the waters are radioactive in a marked degree, and that the salutary effects of the waters are now generally attributed to radioactive substances in the gaseous form. Does such a condition prevail in the Jemez Hot Springs? This is a bit of research for some later investigator to undertake.

THE MEDICINAL VALUE OF THERMAL WATERS

The curative effects of thermal waters are undoubtedly due, to a large extent, to their stimulating effect on the excretory organs of the skin and kidneys. To understand this fully, we have only to examine the routine through which a patient passes at these thermal resorts. The pores are first thoroughly opened and sweating begun by immersing the patient in hot water for from three to ten minutes. The patient is then placed in the sweating room for about five minutes and at the same time drinks copiously of hot water. This treatment, of course, produces profuse perspiration. After this the patient is wrapped in blankets and passed to a warm room for twenty to thirty minutes where the perspiration runs off in streams. After this the patient is rubbed down and allowed to dress. A desire to urinate soon comes. Thus we see that the system is thoroughly flooded with water and washed out each day, and that tissue changes take place with wonderful rapidity. It is no wonder then that the uric acid, syphilitic poisons, and other materials of disease and mercurial and other metallic poisons are soon eliminated from the system. With such effects as those mentioned above, hot baths must be of value in the treatment of rheumatism, gout, syphilis, neuralgia, etc.

THE MEDICINAL VALUES OF THE VARIOUS SALTS AND GASES USUALLY PRESENT IN MINERAL WATERS

The following pages on the medicinal value of the various salts and gases usually found in mineral waters have been taken directly from Mr. J. K. Haywood's "Analyses of the Waters of the Hot Springs of Arkansas."

CARBONATES AND BICARBONATES.

One of the most important groups of mineral waters are the alkaline waters, which are characterized by the presence, in predominating quantities, of one or more of the alkaline or alkaline earth carbonates. These are the carbonates or bicarbonates of sodium, potassium, lithium, calcium, and magnesium. In case iron is present in large quantities as the bicarbonate we have water belonging to the chalybeate class. Since these waters are alkaline they are excellent remedies in cases of sour stomach and in sick headaches which arise from acid dyspepsia. They act very markedly on the mucous membranes, increasing the flow of the gastric juice and other digestive fluids, and are consequently of use in many cases of indigestion. In conjunction with the sulphated salines they give excellent results when used in the treatment of catarrhal conditions of the stomach and intestines. Such waters correct acidity of the urine, markedly increase the flow of the urine and help to dissolve uric acid deposits. They are, therefore, of value in cases of rheumatism and gout.

Sodium Carbonate and Bicarbonate. Sodium carbonate or bicarbonate appears as a normal constituent of the blood, lymph, and nearly all secretions of the mucous membranes. Where conditions arise that cause these fluids to become acid, waters containing carbonate and bicarbonate of soda are of value in counteracting the effect. Waters containing either of these substances have been used with excellent effect in the treatment of acid dyspepsia and diabetes.

Potassium Carbonate and Bicarbonate. Potassium carbonate and bicarbonate are readily soluble in water. The bicarbonate is the one usually present in mineral waters. The properties of this salt are very much the same as those of sodium bicarbonate. It increases the flow of urine and corrects acidity of the bodily fluids.

Lithium Carbonate and Bicarbonate. Lithium carbonate is very sparingly soluble in water, while the bicarbonate is quite soluble. It is in the latter form that lithium is most often reported in mineral waters. This compound is most frequently used in cases of rheumatism and gout, where it forms a very soluble urate, which is easily eliminated from the system.

Magnesium Carbonate and Bicarbonate. Magnesium carbonate and bicarbonate are mild laxatives and are perhaps the best of all carbonates and bicarbonates in correcting an acid condition of the stomach, and curing sick headaches caused by constipation.

Calcium Carbonate and Bicarbonate. Calcium is usually present in waters as the bicarbonates. Both of

these compounds are quite different in their effects from the other carbonates and bicarbonates mentioned. While the others are evacuant and promote secretions, the calcium compounds constipate and decrease the secretions. Very obstinate cases of chronic diarrhea have often been cured by a sojourn at a spring rich in calcium bicarbonate.

Ferrous and Manganous Bicarbonates. Neither iron nor manganese ever occurs in mineral waters as the carbonates, but usually as the bicarbonate. Both of these compounds have practically the same effect. When taken internally, they are dissolved by the gastric juice and taken into the blood. They increase the appetite and the number of red blood corpuscles. It will thus be seen that such waters give excellent results when used as a tonic or in cases of anaemia. Too long continued use of waters rich in bicarbonate of iron or manganese results in constipation and in derangement of the digestion.

CHLORIDES.

Chlorine occurs in waters as chlorides, in combination most frequently with sodium, potassium or lithium, and sometimes with calcium, magnesium or iron. The chlorides form the basis of that large group of mineral waters, the muriated salines.

Sodium Chloride. Sodium chloride occurs in almost all mineral springs to some slight extent, but in the muriated saline waters it occurs in large quantities as a predominating constituent. Waters containing large quantities of this substance are chiefly used in

giving baths, which increase the action of the skin, and by absorption through the pores serve as a genuine tonic. Taken internally the flow of the digestive fluids is promoted and the appetite increased. Putrefactive changes in the intestines are also prevented. In large doses sodium chloride increases the flow of urine and the amount of urea present in the same.

Potassium Chloride. Potassium chloride has very much the same effect on the human system as does sodium chloride.

Lithium Chloride. Lithium chloride has practically the same effect as lithium carbonate and bicarbonate mentioned above.

Magnesium Chloride. Magnesium chloride is often used medicinally as a cathartic and to increase the flow of the bile.

Calcium Chloride. Calcium chloride occurs in a number of muriated saline springs. It is used in cases of general debility as a tonic. It increases the flow of urine and perspiration and waters containing it are used in the treatment of scrofulous diseases and eczema.

Ferrous Chloride. The occurrence of ferrous chloride in mineral waters is rather rare. When present, however, it acts as a tonic and in general has the same effect as the ferrous bicarbonate already mentioned.

Ammonium Chloride. When used internally, ammonium chloride has the stimulating effect of ammonia. It is used in nervous cases such as ovaralgia, sciatica, and other neuralgic disorders. In congestion of the liver its use has been beneficial. Externally it

is used as a wash for ulcers and sores. It, however, seldom occurs in springs in large enough quantities to be of any value.

SULPHATES

Sulphates are frequently found in mineral waters and when present in large quantities give rise to that large class, the sulphated salines.

Sodium and Magnesium Sulphates. Sodium and magnesium sulphates, or glauber and epsom salts, respectively, in small doses act as a laxative, in large doses as a cathartic. They are both valuable in increasing the flow of the intestinal fluids and in increasing the flow of urine accompanied by an increased elimination of urea. Waters containing these salts are of great service in eliminating syphilitic, scrofulous, and malarial poisons of the system and in eliminating mercury and other metallic poisons. Persons suffering from obesity, derangement of the liver, and Bright's disease are perhaps the most benefited by this class of waters. It must be borne in mind that such waters should be used with great care by the feeble and anaemic.

Potassium Sulphate. Potassium sulphate is frequently present in mineral waters, but in smaller quantities than the magnesium and sodium salts. Its action is practically the same as the other two sulphates mentioned above.

Calcium Sulphate. Calcium sulphate occurs in a great many mineral waters, and is the component that

gives them the property of permanent hardness. It is not used medicinally.

Iron and Aluminium Sulphates. Iron and aluminium sulphates are usually found associated with each other in mineral waters. They are both partial astringents. The waters containing iron sulphate are also used as tonics, but this is not nearly as good a form in which to give the iron as is the bicarbonate. Because of their astringent action, waters containing these two substances have been used with success in treating locally inflamed parts of the mucous membranes and ulcers on the outside of the body.

IODIDES

The iodides are usually reported in mineral waters as the potassium or sodium salt. They are alterative in effect and are consequently used in the treatment of scrofula, rheumatism and syphilis. While drinking waters containing iodides the flow of urine is very much increased and mercurial and other metallic poisons are rapidly eliminated from the system.

BROMIDES.

Bromides act as alteratives in much the same way as iodides but not to so marked an effect. They also act as sedatives.

PHOSPHATES.

Phosphates in mineral waters are usually reported in one of three forms; viz., sodium, iron, or calcium phosphate. The sodium phosphate acts as a mild laxative, the iron phosphate as a tonic, and the calcium

phosphate as a medicine in those conditions of the body where lime salts are deficient, as rickets, etc.

BORATES

Boric acid is not a very common constituent of natural waters, but is found as the sodium salt in springs of southern California in large amounts. Applied as a douche in catarrhal conditions of the uterus it is of value.

NITRATES

Any nitric acid that may appear in any water is usually reported as sodium nitrate. This compound does not usually occur in waters to a marked extent unless they are contaminated. When present in large enough amounts it increases the flow of urine and acts as a purgative.

SILICA.

Silica appears in mineral waters both as free silica and as silicates. The medicinal value of silica has not been thoroughly investigated.

GASES.

The gases that usually occur in water are nitrogen, oxygen, carbon dioxide, and hydrogen sulphide.

Nitrogen and Oxygen. Nitrogen and oxygen are present in all waters that have come in contact with the air. On account of the limited solubility of both they cannot occur in waters in very large quantities. Neither of them, when present in waters, has any medicinal value.

Carbon Dioxide. Carbon dioxide is present in all natural waters to some extent, but in some springs the amount is very large, thus giving rise to that large class of carbonated waters of which the Saratoga Springs furnish a good example. Such waters are extremely palatable and large quantities can be drunk without the full feeling, which so often follows copious drinking of water. In moderate quantities such waters increase the flow of saliva, promote digestion, and tend to increase the flow of urine. Obstinate cases of nausea can be often relieved by the use of small quantities of highly carbonated waters.

Hydrogen Sulphide. Hydrogen sulphide is present in many natural waters, giving to them the odor of decayed eggs and forming that large class, the sulphureted waters. When such waters are taken internally they act as an alterative and are consequently of value in the treatment of syphilitic diseases. They increase the activity of the intestines, kidneys, and sweat glands, so are of much use in the treatment of rheumatism and gout. Excellent results have been obtained when these waters were used in treating many skin diseases and malaria.

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